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FEATURES OF PHOTOCURRENT RELAXATION IN SENSOR-BASED CdS CRYSTALS OR FEATURES OF PHOTOCURRENT RELAXATION IN CRYSTALS WITH FAST AND SLOW RECOMBINATION CENTRES

The fast relaxation of the photocurrent associated with electronic processes has been explored. The external factors effect has been investigated. It was shown that in contrast to the accepted view of the phenomena, the of carriers' transitions mechanism includes thermal excitation in sensitivity centers, and only then transition to the free state.

The study of semiconductor devices operating in the infrared part of the spectrum attracts attention in connection with their applications for communication, diagnostics, radiation sensors, in technological processes, for data-transmission systems, in medicine, in military science, etc.

One of the most promising materials for the production of such electronic devices are semiconductors of A^2B^6 group due to cheapness of the substances used, well-designed fabrication technologies, and also due to high photosensitivity of the devices based on such materials.

One of the typical specimen of these binary compounds is cadmium sulfide. For many years, CdS crystals are of considerable interest owing to high photoresponse (the ratio of light to dark conductivity up to eight orders of magnitude), the optimal (~ 5.7 nm) lattice constant, the comparative ease of electrical contacts plating, as well as to a significant solubility coefficient for most doping agents. Due to well-established properties, in some cases, such crystals are used as a model material to clarify the nuances of photoelectric processes.

At the same time this semiconductor belongs to a class of large-gap semiconductors. Its band gap width (2.42 eV), providing the most part of the positive operating properties, including the above, significantly limits range of spectral sensitivity. Even at the expense of its improper excitation it can be extended to long wave region only up to 980 - 1000 nm. Further extension up to 1600 nm (twofold) can be achieved for crystals doped both with fast and slow recombination centers.

The specific feature of such samples is a presence of the photocurrent infrared blanking effect through the joint operation of the recombination centers. The elements' sensitivity does not decrease, as it usually happens with direct current measurements, but also can significantly increase as the relative change of the current is measured instead of the current itself.

The photocurrent infrared blanking reduces current magnitude formed by the free carriers, excited by light from the proper absorption region, when sample is additionally subjected to long wavelength lighting.

The wave length of suppressing light is usually in an infrared part of the spectrum. Therefore the effect is called photocurrent infrared blanking. For the first time this mechanism was suggested by A.Rouz.

The A.Rouz' model is based on the process of a charge carriers release from traps. In this case, after the light excitation from the local center, nonequilibrium carrier does not participate in the current formation immediately. Depending on the applied electric field and temperature, it stays for some time in the vicinity of the center. It is energetically favorable for such carrier,

of course, to return into the trap. The change of trap's charge state after the excitation event also promotes this process. Such free-capture oscillations, probably repeated, do not affect measured electric current, as the spatial position of such charge carriers is unchanged. For this reason, these stages of excitation remained unexplored.

As a tool to study these oscillations we chose the photocurrent infrared blanking effect.We believe that this approach has several advantages.

First, if the crystals under consideration are sufficiently saturated with S- and R-centers, the distance between these centers is small. In this case, holes, knocked by infrared light from centers of slow recombination, after passing only a few crystal lattice cells will hit the S-centers and affect the current. Moreover, if the S-and R-centers are distributed uniformly, the free path length will be more or less fixed. In ordinary situation, these processes are concealed by scattering, random trap captures, other channels of recombination, etc.

In addition, the features of the infrared blanking allow to change independently both parameters of current-forming self light, and the intensity and spectral composition of the infrared light, responsible only for the holes release.

Finally, the effect of IR-blanking allows identifying and investigating the mechanism of carriers' emission from a specific class of the centers, whereas in the usual case we have to deal with a range of traps, depletion processes of which obscure each other.

These features of the infrared blanking make it a sensitive and flexible method for studying the fine details of improper carriers photoexcitation.

The present study aims to investigate features of the carriers excitation from bound to the conductive state using the photocurrent IR blanking effect and the features of current formation.

In the paper [1] the long-time relaxation of the photocurrent (about 10^5 - 10^4 seconds per day) in short samples of cadmium sulfide with IR-blanking under illumination by their proper light is described. A model that explains such relaxation is also suggested there. When crystals are stored in the dark for a long term deep R-centers (1.1 eV), gradually losing charge, are retracted by barriers field into the spatial charge region of electrical contacts and accumulate there. At the subsequent illumination they diffuse towards the crystal center. In this case, the photosensitivity of this region increases, photocurrent increases as well.

We also observed a similar relaxation which authors [1] associated with migration of ions in the crystal. In accordance with the techniques proposed in this article, measures to eliminate such change of the photocurrent were implemented in the sample preparation. The samples were kept for a long time on their proper light.

In the article [2] the middle-time (10^3-10^2 seconds, tens of minutes) relaxation of proper current was studied. The complicated form is explained by additional mechanism of the electrical contacts' spatial charge region shape change due to external voltage applied. However, as before, it was supposed that the photocurrent formation is controlled by the spatial redistribution of the crystal impurities.

In this regard, it is interesting to study the photocurrent change for the periods, excluding influence of ionic processes — 10^1-10^2 sec (tens of seconds, up to several minutes). In this case, the sample is illuminated by its proper light of varying intensity (Fig. 1A). For ease of comparison, all graphs are shifted to the

$t = 0$.

Usually photocurrent relaxation is measured from the initial state, i.e. darkness, to completely steadied value, i.e. saturation on graph I_{ph} (t). In this case, only one value of light intensity is used.

It is clear that the process of electrical current change includes at least two fundamentally different phases. In the initial phase, the photoexcitation of free carriers occurs, most of which fills existing traps and recombination centers. In our case, there are, at least, effective R-centres for this purpose.

The nonequilibrium charge capture process dominates for small values of light intensity, when the number of absorbed photons is less than traps concentration. Conditions are unfavorable for the formation of the photocurrent. On the contrary, the final stages of relaxation occur already in conditions of quasi-equilibrium for capture-

emission processes. In our samples, it happens not less, than in four channels: besides always present sticky centers, recombination at the S-centers occurs, as well as captures and emissions from ground and excited states of R-centers and intracenter transitions as shown in Fig.2b.

Exactly this complex ensemble of interactions was a main subject of research. Therefore, measurements were carried out in the conditions of already existing intensity of proper light and steady photocurrent during the transition to the higher intensity. The additional lighting switching on is considered t = 0 (Figure 1A).

Observations were compared with the reverse process, when the intensity decreased to the base value. In this case, the competing process determines the system behavior — centers are depleted. Indeed, at measurements in low lighting conditions, we observed rather widened relaxation region on the $I_{ph}(t)$ graph. At the same time, the reverse relaxation appeared faster.

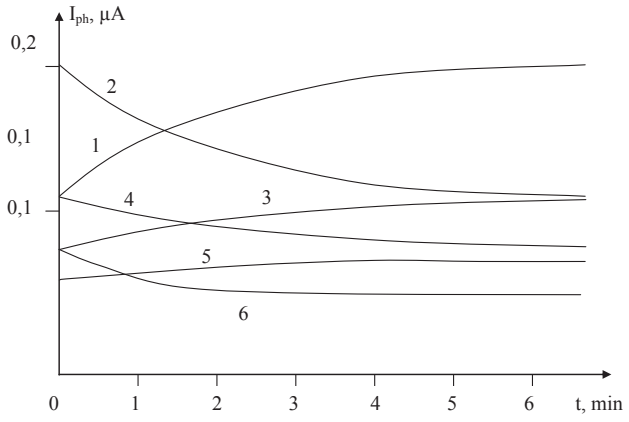

Fig. 1A. A photocurrent relaxation during the change of proper light intensity: 1. — from 4.25 to 9.8 lux; 2. — from 9.8 to 4.25 lux; 3. — from 1.35 to 4.25 lux; 4. — from 4.25 to 1.35 lux; 5. — from 0.6 lux to 1.35 lux; 6. — from 1.35 to 0.6 lux.

For the transitions from low to high lighting conditions at large luminous fluxes, in addition to the natural increase of the photocurrent absolute values, the increase of the growing component over time was insignificant, due it's being determined not by lighting parametres, but the presence of empty states in the traps. The declining component of the $I_{ph}(t)$ dependence was delayed to a bigger extent, as it is determined by the greater charge stored in the traps.

Finally, for the relatively high light intensities, as shown in Figure 1A, the photocurrent magnitude itself depended on intensity of used light. Dynamics of its change — both increase and decrease, starting with two minutes, appeared identical. By superimposing the graphs it can be shown, that these parts of the curves coincide.

In addition to this, the relaxation time from the initial value for the decrease to the initial value for the growth (Fig. 1A) also increased with light intensity increase.

Note that the method of photocurrent relaxation analysis in the separate measurement of the stepwise light intensity is used for the first time.

The short time region, that is less than 2 minutes, appeared dependent on the temperature at which the measurement was made. The essential curve shapes are shown as Figure 1B.

Graphs on Figure 1b were normalized to the saturation point. That is, for the convenience of comparison, the value of the current in the saturation area in both cases was taken as 100% with the corresponding conversion of currents in other areas. Actual absolute values of a current decreased with temperature increase, value in the saturation area, and the current value both.

To avoid rapid reduction of currents associated with the effect of temperature blanking [3], which is not considered in this study, we used the temperature range below 50-60 ° C, typical for the beginning of T-blanking.

As seen in Figure 1B, the temperature increase leads to a noticeable rise of relaxation in 2-3 times. Taking into account approximately 1 sec durations of current evolutions, we related observed changes to electronic processes.

When proper light illuminates sample release of nonequilibrium charge carriers occurs. A certain number of them are involved in the photocurrent formation, but significant part, especially in the initial moments, are spent on filling of deep traps. It is obvious, that the amount of such carriers captured by traps is great at first, as traps were empty. But eventually it is reduced, as traps are filled.

This provides an increase of free state carriers, with the corresponding relaxational photocurrent increase.

At the same time the competing process occurs - as traps are filled at a given temperature the number of thermally emitted carriers increases.

In general, the presence of a plateau is characterized by approximate balance of carriers captured by and emitted from traps. With temperature growth at the same intensity of captures a number of thermal emissions increases. This provides faster saturation (see Fig. 1B).

To observe the photocurrent relaxation under influence of the long-wave radiation, wavelengths corresponding to the maxima of blanking - 960 and 1380 nm (fig. 2.A) were used. Optimal intensities of proper light and blanking light were set according to [4]

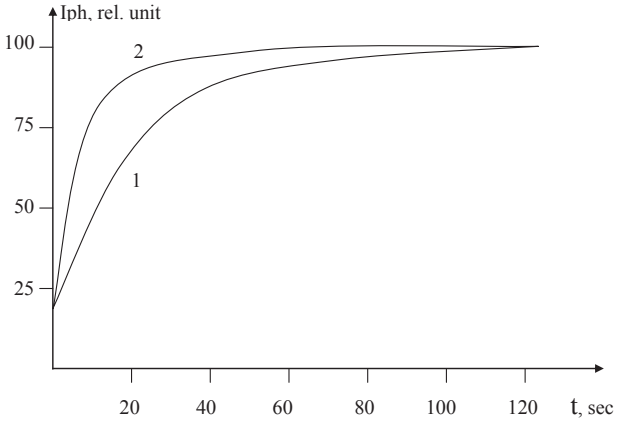

Fig. 1B. Plot of the short time current relaxation
1. — at t ° = 17.5 °C; 2. — at t ° = 43.5 °C.

Fig. 2.A. Temporal photocurrent changes in the blanking maxima.

With the constant exciting light after the relaxation of photocurrent I_0, the infrared illumination was turned on, preset on a wavelength of the corresponding blanking maximum and photocurrent l time dependence was measured.

Both curves start from the same point corresponding to the value of proper excitation. With the infrared lighting photocurrent blanking starts and the current decreases — the curve 1, corresponding to a wavelength of 960 nm, is above the curve 2 for the wavelength of 1380 nm and takes longer to reach saturation.

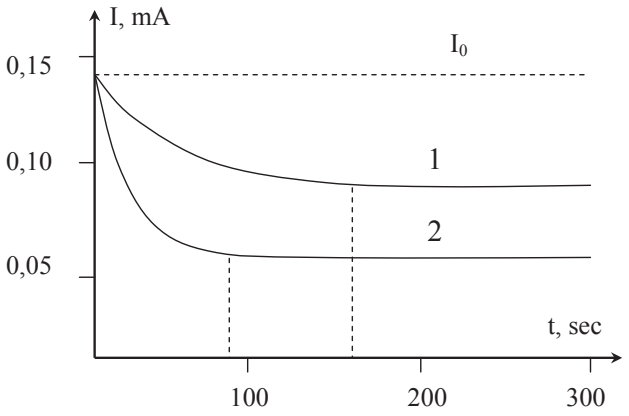

Fig. 2.A. Temporal photocurrent changes in the blanking maxima.

This is explained as follows. Figure 2.B shows the band diagram, where the transitions from the ground state of R-centers correspond to curve 1, and the transitions from the R ‘correspond to curve 2.

Since there is a thermal transition from level R to level R’, the probability of transition from level R’ is greater than from level R. This explains the fact that the curve 2, corresponding to the transition R’, is lower than curve 1, corresponding to the transition from the levels R.

As seen in Figure 2.A, curve 2 reaches saturation faster. This is due to only one process, namely the transitions from the R’. At the same time, curve 1 is due to transitions from the R and R’, plus the thermal transitions inside the sensitivity centers from the ground to the excited states. In addition, as noted above, there is a probability of inverse capture of a hole from the valence band by R centers. In general, the existence of such complex combination of processes accounts for more delayed front of the observed curve.

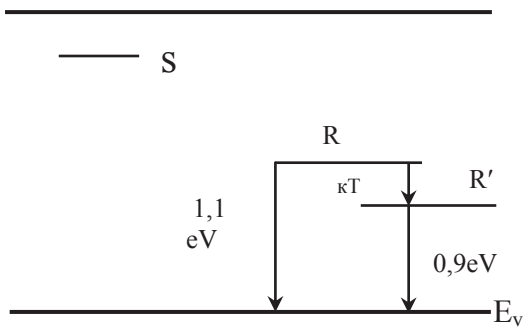

Fig. 2B. Model of phonon-photon transitions involving excited states of R — centers.

Thus, the considered model suggests greater holes population on R' levels due to the thermal transitions from the ground state of R-centers to R'. It contradicts with R.Bjub's zonal model [5] which is based on the opposite mechanism of holes release — intracenter optical excitation with activation energy 0.9 eV followed by thermal excitation in the band with energy of 0.2 eV.

These data provide additional evidence for alternative model presented in the paper [6].

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Abstract.

The fast relaxation of the photocurrent associated with electronic processes has been explored. The external factors effect has been investigated. It was shown that in contrast to the accepted view of the phenomena, the of carriers' transitions mechanism includes thermal excitation in sensitivity centers, and only then transition to the free state.

Key words: relacxation, photocurrent, recombination.

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Драгоев А. А., Ильяшенко А. С., Каракис Ю. Н., Куталова М. И., Бабинчук В. С.

ОСОБЕННОСТИ РЕЛАКСАЦИИ ФОТОТОКА В КРИСТАЛЛАХ С ЦЕНТРАМИ БЫСТРОЙ И МЕДЛЕННОЙ РЕКОМБИНАЦИИ

Резюме.

Исследована быстрая релаксация фототока, связанная с электронными процессами. Изучено влияние на неё внешних факторов. Показано, что в отличие от действующих представлений, процесс перехода носителей включает в себя сначала термическую активацию на возбуждённые уровни центров чувствительности, а затем в свободное состояние.

Ключевые слова: релаксация, фототок, рекомбинация.